Forward and Inverse Kinematics analysis of the ABB IRB 6700 Industrial Robot

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Abstract: This paper presents a comprehensive kinematic analysis of the ABB IRB 6700 industrial robot using both forward and inverse approaches. Understanding the robot's kinematics is essential for developing accurate control algorithms and ensuring precise motion. A numerical model for forward kinematics is derived using the Denavit–Hartenberg (D-H) convention and validated with RoboAnalyzer simulation software. Inverse kinematics is addressed through both analytical and geometric methods to compute joint angles required for a desired end-effector position. The methodology developed is applicable to other serial robot manipulators as well. The study demonstrates the use of RoboAnalyzer and MATLAB for validating kinematic equations, facilitating offline programming and visualization.

Keywords: ABB IRB- 6700 industrial robot; D-H parameters; Forward Kinematics; Inverse Kinematics; RoboAnalyzer

1. Introduction

Industrial robot use and demand have significantly increased over the past few years. Robotics technology has improved efficiency in industrial processes by cutting cycle times, improving quality, and lowering production costs and material waste. They are utilized in a very broad range of applications and are employed for a variety of tasks including painting, assembling, machining, picking, and placing[1]. These industrial robots are in such great demand primarily due to their precision and productivity[2]. Owing to their adaptability and programmability, robots are widely utilized across various applications in the manufacturing industry. With aid an industrial robot, several advantages may be realized. They can produce findings with a high degree of accuracy and few errors[3]. There are several fundamental uses for industrial robots, However, it is the robot manipulator which is most frequently employed in manufacturing and assembly facilities. Robot manipulators are mostly employed in medical applications lIKne remote surgery because of their precise mobility. The majority of these robot manipulators are humanoids or anthropomorphic, yet from a structural standpoint, several of them may be characterized as electromechanical. Generally speaking, a robot operator copies the human heart, brain, arm also referred to as the "3Hs.". Robotic manipulators often referred to as robotic arms or manipulators are mechanical devices made to manipulate items in their surroundings in order to carry out a variety of activities. Common applications for these manipulators include assembly lines, manufacturing, industrial automation, and even research and development environments. Robot manipulators are often composed of numerous interconnected segments or links joined by joints. These joints provide the manipulator a range of motion and degrees of freedom for carrying out tasks. The end effectors, or the component that interacts with the items being handled, is located at the end of the manipulator. Depending on the exact requirements of the operation, end effectors can take many different forms and include grippers, suction cups, welding tools, cameras, or sensors. Robot manipulators find extensive usage in pick-and-place tasks in manufacturing, product assembly (e.g., autos, electronics), welding, painting, packing, material handling, and even space exploration and surgery. Robotics advances, such as those in materials, sensors, actuators, and control algorithms, continue to expand the capabilities and adaptability of robot manipulators, which makes them more and more essential to a variety of sectors and domains.

Point orientation and teach pendant enable robot manipulators to follow a predefined path. The end-effectors then track this path. Time determines the working zone, often known as the Cartesian space. These industrial robots consist of a system of rigid bodies called links, which are joined by kinematic joints. These joints come in

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a variety of forms that provide relative mobility of some sort between the two links.

A kinematic chain made up of these links, that are joined by kinematic joints. These kinematic chains may have branches, openings, or closures. The sequence of joint transformations (JK) the forth route from end to end (input to output) point in open kinematic chains determines the output point's position and orientation[4,5]. Consequently, a special solution is offered by the Forward Kinematics (FKN) of open kinematic chains, and this research is known as Kinematic Analysis[6]. On the other hand, if the coordinates of the output point are known, then to identify the changes of each connecting joint is an Inverse Kinematics (IKN) problem and is within scope of Kinematic Synthesis. It produces multiple potential solutions that can be contrasted according to additional criteria[7]. Calculate all significant points in a Cartesian coordinate in order to carry out smooth operations. In inverse kinematics, trajectory positions are transformed from Cartesian coordinates to joint coordinates. Inverse kinematics, to put it simply, is the process of figuring out the joint angles needed to obtain the desired position and end effectors (EE) orientation[8]. Only when every aspect of the processes and variables is taken into account can the precision be reached. The development link between robot joint angles and the ultimate placement and orientation of the EE is connected to the forward kinematics approach. In the end, the joint angles, points, and locations are used to establish EE's position[9]. Manipulators without taking into account the forces or torques that creates the motion, kinematics is the study of motion, or kinematic parameters[10]. Prior to assigning a robot to a given task, the end-effectors location and orientation with respect to the base must be determined. It is required to ascertain the relationships between the two sets of configurations, which are described by the six Cartesian variables.

These variables are governed by the joint movements of the robot. Consequently, forward kinematics (FKN) and inverse kinematics (IKN) are the two basic activities that make up robot kinematics[10]. FKN is the transition from world space to joint space. Conversely, IKN describes the transition from joint space to global space[11]. A homogeneous transformation matrix (TM), which must be created, determines the tool frame's orientation and location with regard to the global reference frame. To fix the difficulty, both FKN and IKN employ the same TM. Pieper provided the first description of a 6R manipulator IKN[11]. He developed iterative numerical methods and used elimination theory to solve an upper limit problem for the total number of solutions. Popular industrial robots IKne the ABB IRB 6700 are employed in a variety of tasks IKne machine tending, material handling, and welding. We must comprehend the kinematic structure and characteristics of this robot in order to do inverse kinematic analysis. A robot of 6-axis with a serial manipulator construction is the ABB IRB 6700. A rotary motor powers each joint, and the robot's end effectors are fastened to the last joint. The kinematics of this kind of robot is often described using the Denavit-Hartenberg (DH) standard.

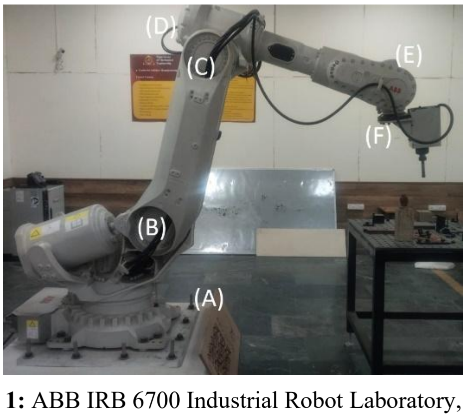

Fig. 1: ABB IRB 6700 Industrial Robot Laboratory, G L Bajaj Institute of Technology & Management, Greater Noida, India

Several studies have investigated kinematic modeling and analysis for different robotic architectures. Raghavan and Roth[17] proposed analytical methods for solving the inverse kinematics of general 6R manipulators, demonstrating the multiple-solution nature of the problem. Pieper's early work also laid the groundwork for solving 6-DOF manipulator kinematics analytically[13]. Saha et al. developed RoboAnalyzer, a simulation tool designed for academic and prototyping use that enables 3D visualization and verification of robot kinematics and dynamics[11,12].

Additionally, Dahari and Tan[9], and Srikanth et al.[4] modeled the kinematics of industrial robots such as the KUKA KR16 and similar manipulators, often using MATLAB-based frameworks for forward and inverse analysis. These approaches, while effective, often focus on simplified models or lack integration between theory and simulation for specific industrial robots. Analytical solutions, particularly Pieper's criterion, provide efficient inverse kinematics for robotic manipulators, enabling real-time control. However, challenges remain[13] in handling redundancy, singularities, and dynamic uncertainties, highlighting the need for robust and optimized kinematic algorithms.

This study addresses the kinematic analysis of the ABB IRB 6700, a high-payload, 6-degree-of-freedom (6-DOF) serial manipulator widely used in manufacturing applications such as welding, arc milling, and heavy-duty material handling[14]. Despite its industrial relevance, limited literature exists that combines both analytical kinematic modeling and simulation-based validation for this specific robot.

Therefore, the objectives of this work are:

To develop a complete forward and inverse kinematics model of the ABB IRB 6700 using Denavit–Hartenberg

(D-H) parameters.
To validate the mathematical models using MATLAB and RoboAnalyzer simulations.
To propose a generalizable approach to kinematic analysis applicable to other 6R robot manipulators.
By bridging theoretical computation with interactive simulation tools, this study contributes to robotic research by offering a reproducible and application-ready methodology suitable for both industrial deployment and academic instruction.
The Robotics and Mechatronics lab at IIT Delhi developed the program Robo Analyzer, which is used in this work to validate the outcomes of FKN and IKN tests carried out by the ABB IRB 6700 Industrial Robot. Graphs show the end effectors trajectories of the robot and the animation analysis.

2. Experimental Setup

As seen in picture 1, the ABB IRB 6700 is an articulated milling six axis (6DOF) industrial robot manipulators. The seventh generation of high payload, high performance industrial robots from ABB Robotics is the IRB 6700 series. The IRB 6700 robot family builds on the well-known IRB 6640 series, which is notable among ABB's robots due to its availability, service-friendly modular design, wide operating range, and high wrist torque. With an emphasis on high production capacity, small size and light weight, easy maintenance. Regardless of the business, the IRB 6700 is excellent for process applications. Typical places include for instance Spot welding, moving objects, and maintaining machinery. The robot's base is fixed, allowing its other connections and end effectors to move freely within the available area. Figure 1(b) displays the dimensions of the robot manipulator as well as the center-to-center distances between the links. The robot's first three major axes are A1, A2, and A3 in Figure 2, because they help with positioning; the other three axes are minor axis like A4, A5, and A6 because these arm help with articulating the end effectors to the target point.
With an armload capacity of 235 kg and a reach of 2.65 meters, this compact robot boasts an upper arm built for integrated dressing packages for arc milling with

Table 1: ABB IRB 6700 Robot Manipulator dimensions[14]

Position	Axis Description	Lengths(mm)
A	(A1)	200
B	(A2)	532
C	(A3)	633
D	(A4)	2276
E	(A5)	1125
F	(A6)	1623
G		1142.5
H		197.5
J		193

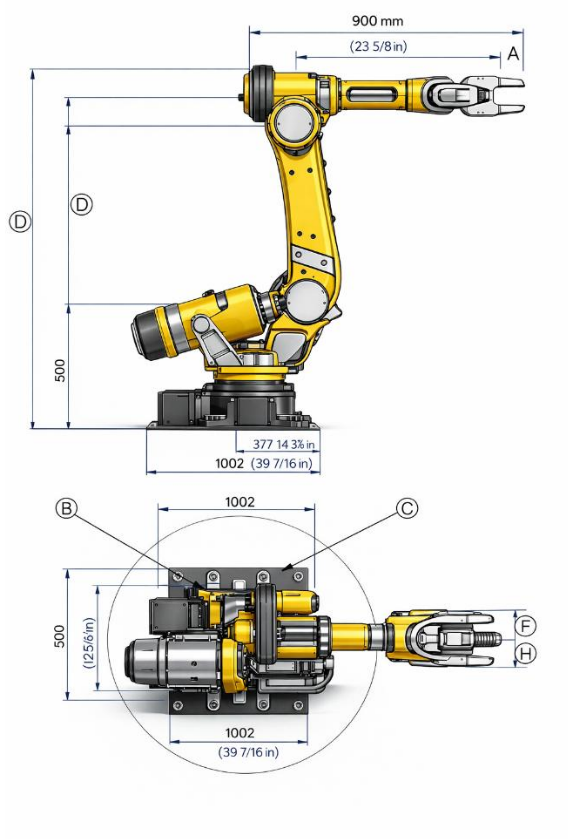

Fig. 2: A three-dimensional 6 DOF ABB IRB 6700Robot manipulator[14]

exceptional precision. The primary use for this kind of robot is arc milling. Because to its numerous technological benefits, including precision, repeatability (0.05 mm position repeatability and 0.35 mm path repeatability), and drivability. The robot is 170 kg in weight. As a result, the forward and reverse kinematic analyses will use this model. In Table 1 robot manipulator dimensions are presented. These measurements give the lengths of each axis between the robot's numerous joints or end effectors and its reference point, which is often the base or another fixed location. To precisely locate and program the robot's motions, this information is necessary.
Three-dimensional configuration of a robot manipulator is shown in Figure 2. There are 6 joint axes and 6DOF in all on the manipulator: The type T joint, joint 1, allows for rotation around the Z-axis. You can rotate along an axis that is perpendicular to the Z-axis at joints 2, 3, and type R. The type T joint, joint 4, allows for rotation around the X-axis. Rotation about the X-axis is possible in joint 6 and around the Y-axis in joint 5. Figure 2 displays the coordinates for each axis when rotation is permitted. Each joint has sensors that detect motion, and a mechanical stopper establishes the minimum and maximum rotational limits for each joint.
A rotation of 3400 (±170°) about axis A1 is permitted for the base axis. There are constraint movements about the rotational axes of other joints. The kinematic analysis was

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conducted using the specified robot setup as the foundation. The following sections give the forward and inverse kinematic analyses that make up this division. Development of the mathematical modeling of the ABB IRB 6700 industrial robot's kinematics is necessary in order to fully understand its forward and inverse kinematics.

3. Forward Kinematics (FKN)

Put numbers, multiple links on a robot manipulator are joined via a prismatic or revolute junction. As a result, each joint will only have one degree of freedom. The relationship between their respective coordinate frames must be established for precisely calculate the end-effector's (EE) position with regard to robot base. Coordinate transformations across the frames linked to each joint during kinematic analysis can be used to accomplish this.

The robot's translation and rotation between neighboring links are represented by transformation matrices. Precise control of a robot's movements relies heavily on the accuracy of the FKN equations and the efficiency of the inverse kinematics solutions. The DH parameters of each joint are used to create its transformation matrix. The ultimate position of the end-effectors can be found by multiplying these matrices in succession from the base to the end-effectors. The mathematical model can be defined by computing the product of the transformation matrices (TMs) of each manipulator joint, allowing for calculation of the end-effector's position relative to the base or any specified reference frame. Determining a joint coordinate system at each joint and a global coordinate system at the robot base are crucial. One of the main methods for assessing the robot's movements is D-H analysis. The TMs between the robot joint axes are written using it. Four parameters with translations and rotations about various axes are involved in these matrices. The ABB IRB 6700 robot's forward and inverse kinematics need intricate computations with transformation matrices and D-H parameters. Forward kinematics determines the position and orientation of the end-effector based on given joint angles, whereas to achieve a desired end-effector position and orientation an inverse kinematics joint angles are required. For simpler settings, analytical approaches can be applied; for more complex cases, numerical methods are required.

The incorporation of these computations into the robot's control system facilitates accurate and effective manipulation, which is essential for a range of industrial uses.

The Denavit–Hartenberg (D-H) analysis, as presented in[12], was used to derive the transformation matrices (TMs) between the robot's coordinate axes.

Four variables are used in these TMs to construct linkages

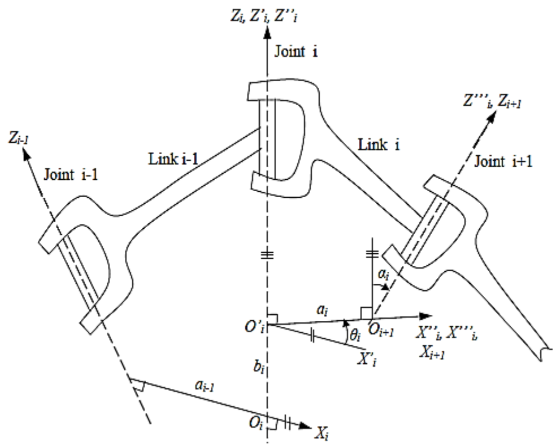

Fig. 3: Frame (i) description with respect to frame (i-1), (12, 13)

Table 2: Description of D-H parameters

Parameters	Description
θi	Joint angle (variable)
bi	Link offset (constant)
ai	Link length (constant)
αi	Link twist (constant)

between links that have translation and rotation axes. Table 2 defines the four D-H parameters with reference to Figure 3. The explanation of these four characteristics follows a certain order, since they are determined from link (i-1) to link (i+1) via link i. The joint offset (bi) and joint angle (θi) describe the respective linear and angular locations of the two links (i-1) and i. On the other hand, the final two parameters—the link length (ai) and the twist angle (αi)—describe the dimensions and form of the link I and stay unchanged.

The kinematic arrangement is a determining factor for the parameters bi and θi. In the case of a prismatic joint, bi is considered a variable, while in the case of a revolute joint, θi is considered a variable. Therefore, one parameter—referred to as the joint variable (JV)—is taken into account as changing based on the kind of joint and its connectivity, such as prismatic or revolute, while other parameters—referred to as "link parameters"—are constant. Assigning the joint's frames is the next step. The Denavit-Hartenberg (D-H) convention must be used to determine the frames of reference for each joint in order to perform kinematic analysis on the ABB IRB 6700 robot. Here, we'll supply the required D-H values and allocate frames according to the standard setup of a 6-DOF robot. For the ABB IRB 6700, these are the procedures and matching D-H parameters. Assign coordinate frames to every connection and joint in the ABB IRB 6700.

Frame 0: Base frame, located at the base of the robot.

Frame 1: Attached to the first joint axis.

Frame 2: Attached to the second joint axis.

Frame 3: Attached to the third joint axis.

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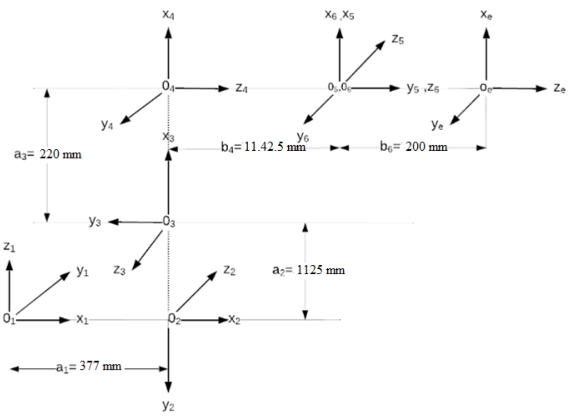

Fig. 4: ABB IRB 6700frame assignments

Table 3: D-H parameters of ABB IRB 6700Industrial Robot [JV: Joint variable]

Links	bi (Joint offset, mm)	θi (Joint angle)	ai (Link length, mm)	αi (Twist angle)
1.	b_1= 780	θ_1 (JV)	a_1=377	-90^0
2.	0	θ_2 (JV)	a_2=1125	180^0
3.	0	θ_3 (JV)	a_3=220	90^0
4.	b_4=1142.5	θ_4 (JV)	0	90^0
5.	0	θ_5 (JV)	0	-90^0
6.	b_6=200	θ_6(JV)	0	0^0

Frame 4: Attached to the fourth joint axis.
Frame 5: Attached to the fifth joint axis.
Frame 6: Attached to the sixth joint axis.
The frame assignments are shown in this simplified form as shown in Figure 4.
Figure 4 shows the frames allocated to the various rotational axes used in the D-H parameter computation. When assigning the manipulator's axis to the frame, the Z axis must first be chosen, and then the X axis' direction must be determined based on how the joints rotate. With the aid of Equation 1, the forward kinematic analysis may be completed. In Table 2, the TM corresponding to the i^{th} joint's D-H parameters is represented by [Mi], whereas the TM of the end effectors with respect to the base frame is represented by [Mee]. [M_{ee}] = Transformation Matrix of the end effectors

$$[M_{ee}] = [M_1] * [M_2] * [M_3] * [M_4] * [M_5] * [M_6] \quad (1)$$

Where,

$$[M_1] = \begin{bmatrix} \cos\theta_1 & 0 & -\sin\theta_1 & a_2\cos\theta_1 \\ \sin\theta_1 & 0 & \cos\theta_1 & a_2\sin\theta_1 \\ 0 & -1 & 0 & a_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$[M_2] = \begin{bmatrix} \sin\theta_2 & \cos\theta_2 & 0 & a_3\cos\theta_2 \\ \cos\theta_2 & \sin\theta_2 & 0 & a_3\sin\theta_2 \\ 0 & 0 & -1 & a_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$[M_3] = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & a_4\cos\theta_3 \\ \sin\theta_3 & 0 & \cos\theta_3 & a_4\sin\theta_3 \\ 0 & 1 & 0 & a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$[M_4] = \begin{bmatrix} \cos\theta_4 & 0 & \sin\theta_4 & a_5\cos\theta_4 \\ \sin\theta_4 & 0 & \cos\theta_4 & a_5\sin\theta_4 \\ 0 & 0 & 0 & a_4 \\ 0 & 1 & 0 & 1 \end{bmatrix} \quad (5)$$

$$[M_5] = \begin{bmatrix} \cos\theta_5 & 0 & -\sin\theta_5 & a_6\cos\theta_5 \\ \sin\theta_5 & 0 & \cos\theta_5 & a_6\sin\theta_5 \\ 0 & -1 & 0 & a_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

$$[M_6] = \begin{bmatrix} \cos\theta_6 & -\sin\theta_6 & 0 & a_7\cos\theta_6 \\ \sin\theta_6 & \cos\theta_6 & 0 & a_7\sin\theta_6 \\ 0 & 0 & 1 & a_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

Regarding the robot base reference frame, the location and orientation of EE are described by the transformation matrix [Mee][15,16]. These matrices are transformed into equations, and MATLAB programming is used to further calculate these equations. In order to avoid the singularity requirements, end effectors trajectories should be drawn in the space and their maximum reach determined beforehand. The point at which robot motion is impacted is known as the robot manipulator's singularity. This is the robot manipulator setup when the end effector's location is blocked. When it comes to robotics, the singularity can sometimes be quickly detected, but other times it must be determined by intricate mathematical formulas. As a result, before analyzing the kinematics, it is important to carefully evaluate the manipulators' singularity. It was necessary to choose the coordinates of the several end effector locations in the space for the forward kinematic analysis. To create the FKN model, a set of eight places, as shown in Figure 5, were selected at random. The position vectors of X and Z from Table 3 are described by positions at wrist center with axis of rotation. With the stop in place, The robot's ability to reach certain orientations and positions would be affected, especially for tasks requiring high precision or wide range of motion in the wrist or tool end. The exact working range would depend on where the mechanical stop is located and the total limits of the other axes involved.
It should be mentioned that since θ_1 is always chosen as zero, there is no Y component to these specific places. The same values were utilized in the MATLAB code, and these places are used to enter in the software used for analysis. As a result, the model's validity has been verified through programming, and the findings and debate that follow reflect this.

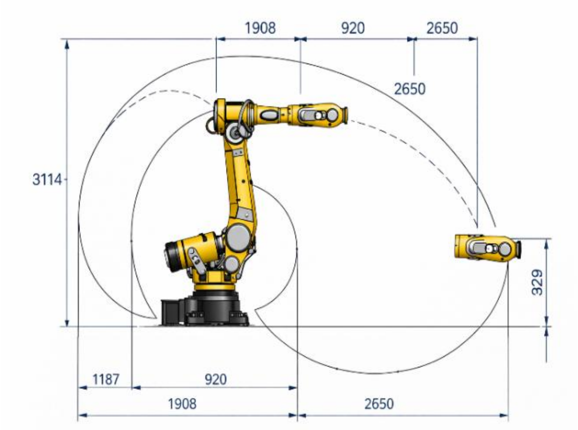

Fig. 5: Wrist center positions with range and extra mechanical stop on axis 3[14)]

Table 4: Wrist center position with axis rotation

Positions	X Position (mm)	Z Position (mm)	Joint Axis 2 Angle (degrees)	Joint Axis 3 Angle (degrees)
P0	881	1242	0	0
P1	161	1792	0	-73.4
P2	484	364	0	+80
P3	1502	452	+90	-73.4
P4	1072	-482	+150	-100
P5	-162	366	+150	+81
P6	246	775	-90	+81
P7	-1181	451	-90	-74.4
P8	-1106	129	-90	-98.7

The spatial volume that the ABB IRB 6700 robot can operate in is defined by its working range, also known as its work envelope as shown in Figure 5.

Since no joint may be rotated to its maximum or minimum degree by 360^0, each joint has a maximum and minimum rotation restriction. Table 4 displays these rotational limitations of motion for several joints. The table delineates the range of motion, both maximum and lowest, that the robot manipulator is capable of executing. We'll utilize this table for IKN analysis going forward. The sections that follow provide a full description of the IKN analysis process.

Table 4 presents the positions of a robotic manipulator, where each row corresponds to a different point (P0 to P8) in the workspace. For each position, the X Position and Z Position (in millimeters) describe the end-effector location, the Joint Axis angle 2 and 3 (in degrees) specify the angles of two joint axes at each position.

P0 to P8: These represent different configurations or waypoints the manipulator must reach.

X Position and Z Position: Indicate the spatial coordinates of the end- effector along the X and Z axes.

Joint Axis 2 Angle: Represent the required angles for Joint Axis 2 and Joint Axis 3 in order to achieve the corresponding position of its effector.

Table 5: ABB IRB 6700range of movement[14)]

Axis descriptions	Type of motion	Range of Movement
A 1	Rotation motion	±170°
A 2	Arm motion	From +150° to -90°
A 3	Arm motion	From +80° to -100°
A 4	Rotation motion	±155°
A5	Bend motion	±135°
A 6	Turn motion	±200°
A 7	Rotation motion	±170°

This data is crucial for controlling the robot's movement, ensuring the accurate positioning and orientation in relation to the base or other reference frames.

Table 5 lists the various joint axes and their corresponding motion types and ranges of motion for a robotic manipulator. Each axis represents a specific movement capability within the robotic arm:

A1, A4, A7: These are rotational motions, where the axis can rotate within a range of +170° to -170° (for A1 and A7) and +155° to -155° (for A4).

A2, A3: These represent arm articulation motions, allowing for controlled movements of the arm within specific angular limits. A2 has a range from +150° to -90°, while A3 allows for motion between +80° and -100°.

A5: This axis enables bending motion, with a range of +135° to -135°.

A6: This axis provides turning motion, with a broader range of +200° to -200°.

These motions are crucial for achieving precise control the robot's movements, allowing the end effector to reach specific positions and orientations to the robot's base. By understanding and calculating the movement capabilities of each joint, one can plan and execute the necessary transformations to move over entire robot's workspace.

4. Inverse kinematics (IKN)

The inverse kinematics problem is more challenging to solve than the FKN. Kinematic analysis of robotic manipulators is the main focus of the IKN robotics problem. For instance, there are certain issues with the IKN. To determine the solution for all possible configurations, it is desired to calculate the movements with respect to each variable to trace the path from the end-effector position to the base position. Since the end effector's settings are unique, there is only one solution to the FKN problem. But in the instance of the IKN, there are multiple answers to the problem, and they must be carefully determined. To find the answer, there are standard and non-traditional approaches accessible. A technique to determine the IKN for a serial 6R manipulator robot has been proposed by Rag van and Roth[17)]. RoboAnalyzer software was integrated into an IKN investigation of a generic 6R serial manipulator[18–19)].

The equation 1 is simplified as follows to get the IKN of the ABB IRB 6700 robot:

$$Mee= M_1 * [Mee]_2; \quad (8)$$

Where, $[Mee]_2 = [M_2] * [M_3] * [M_4] * [M_5] * [M_6]$
According to Figure 5, [Mee]2 in the aforementioned Eq. 2 corresponds to the TM of the EE with regard to frame 2. Note that when joint 1 rotates, the EE point always lies in the XY plane of frame 2, hence θ1 is not included in this expression. This is solely a result of the architecture of the robot. As a result, the computation of the rotational angles of joints 2, 3, 4, and 5 can be reduced to a planar issue. Accordingly, [Mee]2 is ascertained as

$$[Mee]_2= M_1^{-1} * Mee \quad (9)$$

In this case, M_1^{-1} represents the TM of joint 1 in relation to joint 2's frame. Keep in mind that M_1 was determined in the FKN by simply multiplying four separate TM, which corresponded to each of the joint 1's D-H characteristics. Similarly, M_1^{-1} can be found by multiplying TMs with respect to each D-H parameter's opposite sign value, maintaining an opposite multiplication order. For $\alpha_1=90^0$, the formula for M_1^{-1} is derived as

$$M_1^{-1} = \frac{Adj(M_1)}{|M_1|} \quad (10)$$

Where;

$$Adj(M_1) = Transpose\ of\ cofactor\ of\ matrix\ (M_1) \quad (11),$$

And

$$|M_1| = Determinantof\ (M_1) \quad (12)$$

$$[M_1^{-1}] = \begin{bmatrix} cos\,\theta_1 & sin\,\theta_1 & 0 & (-\,sin\,\theta_1\, a_2\, sin\,\theta_1 - cos\,\theta_1\, a_2 cos\theta_1) \\ 0 & 0 & & -1\, a_1 \\ -sin\,\theta_1 & cos\,\theta_1 & 0 & (tan\theta_1 a_2 cos\theta_1 - a_2 sin\theta_1) a_2 cos\theta_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (13)$$

The Z component of the TM in the final column of equation 4 is absent. This makes it very evident that the end effector always stays in frame 2's XY plane.

$$Let\ V = [V_x, V_y, V_z],\ V' = [V_x', V_y', V_z']\ T. \quad (14)$$

One way to simplify the IKN of the ABB IRB 6700robot arm is as follows:
Angle θ1 has no effect on V z and has solely contributed to V x and V y. The geometry allows for the determination of θ1 as follows:

$$\theta_1= a\ tan^2\ (V_x, V_z) \quad (15)$$

The origins of frame 2's XY plane are where the coordinate systems for frames 2 through 6 originate. Additionally, this plane rotates in relation to frame 1's YZ plane. Furthermore, the EE's location in frame 2 is unaffected by the last joint 6's rotation. Consequently, the following represents the expression for the EE point in frame 2 (V'):

$$[V']= [M_1^{-1}] * [V] \quad (16)$$

$$[V'] \begin{bmatrix} Vx' \\ Vy' \\ Vz' \\ 0 \end{bmatrix} = \begin{bmatrix} cos\,\theta_1 & sin\,\theta_1 & 0 & -a_2 \\ 0 & 0 & -1 & a_1 \\ -sin\,\theta_1 & cos\,\theta_1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Vx \\ Vy \\ Vz \\ 0 \end{bmatrix} \quad (17)$$

The computations for joint angles θ_2, θ_3, θ_4, and θ_5 can be performed similarly to a planar 3R serial robot as derived (11). Once [V'] is established from the actual input for IKN [V]. The MATLAB program was used to obtain the IKN results, which were then compared with the RoboAnalyzer software results for the same DH parameters.

5. Results and discussions

The robot's inverse kinematics (IKN) and forward kinematics (FKN) are calculated using the RoboAnalyzer program. RoboAnalyzer software findings are compared with forward kinematics computed using MATLAB and the suggested mathematical model. Figure 7 displays the end-effector coordinate graphs generated by RoboAnalyzer, while Figure 8 displays the MATLAB plots. Since the results match exactly, the suggested model is validated. According to the results, the end-effector's y-coordinate will start out at zero. This is dependent upon the initial joint coordinates that are selected.
The cycloidal joint trajectories considered for the forward kinematics is given as[11)]:

$$\theta_i = \theta_i(0) + \frac{\theta_i(T)-\theta_i(0)}{T}\left[t - \frac{T}{2\pi}\sin\left(\frac{2\pi}{T}t\right)\right] \quad \text{for } i = 1,2,3,4,5,6. \quad (18)$$

The primary benefit of choosing a cycloidal trajectory is that the robot won't jerk or vibrate when it starts and stops at zero acceleration. The robot moves quite smoothly as a result. Thus, this trajectory is best appropriate if the journey period is chosen to be quite large. In addition, the overall energy usage is lower than on other paths. It is simple to assess a chosen robot created in the FKN and IKN without the need for any standard MAT lab programming[20, 21)]. The integration of RoboAnalyzer was used to determine the FKN and IKN of the ABB IRB 6700 robot. Once the D-H parameters are defined, the robot linkages' joint trajectories are produced as a graph. The results of the robot link simulation can be shown as a graph. It was believed that all structural strength requirements were met and that there was no joint distortion in the links[22,23)].

5.1. Forward Kinematics Analysis of ABB IRB 6700Robot

The robot's overall performance and response time are affected by the computing complexity of both forward and inverse kinematics algorithms, particularly in high-speed applications[25, 26, 27].The D-H parameters from the previous section are first input into the software to obtain the 3D model of the robot, as illustrated in Figure 6, in the FKN analysis of the ABB IRB 6700 Robot. All rotational axes in this model have a frame associated to it. The software is executed using the chosen total duration and step count for the FKN analysis. The trajectories of the EE are simply acquired after the FKN analysis is finished.

A CAD model was utilized instead of the actual robot because the program did not include this model, and its shape was not precisely the same. The D-H parameters is length between links and center-to-center are defined by the and are provided in an earlier section of Table 3, therefore this had no effect on the robot's kinematic analysis. As illustrated in Figure 7, is executed for a number of steps and work cycles once CAD model has been created in the software. This simulates the robot and yields the EE's trajectory.

The cycloidal curve was taken into consideration when selecting the EE's initial positions in X, Y, and Z coordinates, which were 1.54, 0, and -0.5. The EE's ultimate location was computed after 5 seconds. It has been observed that MAT lab programming was used to compute the same values and trajectories. This comparison supports the FKN analysis's mathematical formulation. Figure 8 displays the analysis and additional link trajectories for the different manipulator joints with regard to time in 5 seconds.

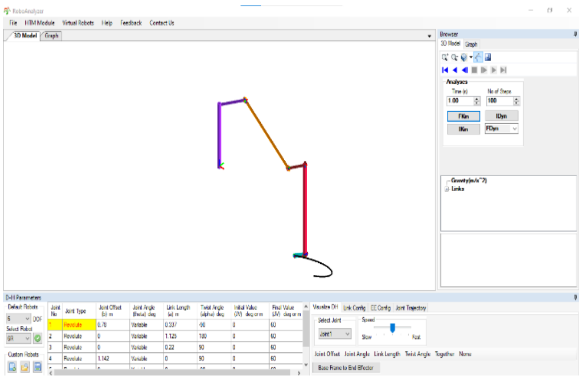

Fig. 6: 3D view of ABB IRB 6700with DH parameters of robot in RoboAnalyzer

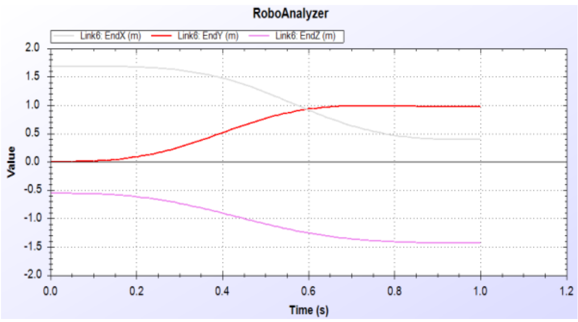

Fig. 7: End Effector Trajectory for ABB IRB 6700 robot obtained in RoboAnalyzer

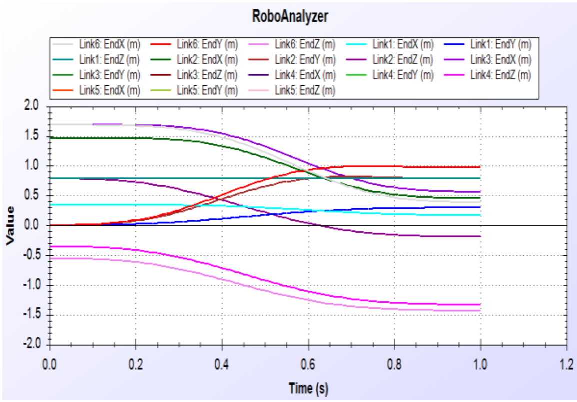

Fig. 8: Links trajectories with respect to time in 5sec

5.2. Homogeneous matrix calculation with respect to base frame[28]

The transformation matrix between the frames connected to the links is shown in this section.

$$[M_1] = \begin{bmatrix} 1 & 0 & 0 & 0.377 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0.780 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (19)$$

$$[M_2] = \begin{bmatrix} 1 & 0 & 0 & 1.125 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (20)$$

$$[M_3] = \begin{bmatrix} 1 & 0 & 0 & 0.220 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (21)$$

$$[M_4] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 1.1425 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (22)$$

$$[M_5] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (23)$$

$$[M_6] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.200 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (24)$$

$$[M_{ee}] = \begin{bmatrix} 1 & 0 & 0 & 1.722 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & -0.562 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (25)$$

5.3. Inverse kinematic ABB IRB 6700robot

Determining the angles of joints required to accomplish a specified position and orientation of end-effector is the process of IKN for the robot.[29,30] Given a desired pose, resolving the inverse kinematics of the IRB 6700, a 6-degree-of-freedom (DOF) robot, entails figuring out six joint angles.[31,32] The ABB IRB 6700 robot's inverse kinematics can be completed using RoboAnalyzer. Orientation, and utilizing the software to calculate and display the joint angles are all necessary steps in doing inverse kinematics for the ABB IRB 6700 robot using RoboAnalyzer. For a variety of industrial applications, this method makes it simpler to design and regulate the robot's movements by streamlining the intricate computations associated with inverse kinematics[33]. Enter the ABB IRB 6700's D-H settings into RoboAnalyzer. This entails defining every joint and link in accordance with the preceding Table 3. In the RoboAnalyzer interface, specify the desired end-effector position (x, y, z) and orientation (roll, pitch, yaw). RoboAnalyzer will solve the inverse kinematics problem using the provided robot model. Because of its complexity, the inverse kinematics problem for the ABB IRB 6700 is usually approached using a combination of analytical and numerical techniques. Following steps were taken into consideration for inverse kinematics by using RoboAnalyzer software.

1) Enter the DH parameters for the ABB IRB 6700 into RoboAnalyzer.
2) Specify exact required position and orientation of the end effector.
3) Use RoboAnalyzer's inverse kinematics module to compute the required joint angles.
4) Using its built-in algorithms, the software will use the robot model to solve the inverse kinematics problem.

The task of inverse kinematics for serial-chain robots is very difficult. Eight solutions are there corresponding to joint coordinates for every end-effector position. Figure 9 displays the outcomes of inverse kinematics using the RoboAnalyzer program. RoboAnalyzer can be used to acquire the inverse kinematics of the ABB IRB 6700 robot once the forward kinematics findings have been received. Since there are several methods for inverse kinematics, the robot has an additional degree of versatility. Assume that the robot must choose the best configuration in order to prevent any kind of mishap if it is operating in a crowded area and there are several configurations available for the same end effector position. The inverse kinematics problem has eight primary possible solutions. We are able to select any two of these solutions to recreate the forward kinematics. For each solution, every joint needs to meet the joint angle range restriction. We feed the end effector values (x=0.1m, y=0.1m, and z=0.1m) to obtain numerous solutions. With the aid of the program, eight solutions in all were produced, and it was discovered that, depending on the working conditions, two of the eight options were workable. Figure 9, which defines the EE position and yields eight alternative manipulator configurations, presents these answers.

6. Conclusions

The industrial robot ABB IRB 6700's forward and inverse kinematics are examined in this work. This work develops a methodology for the kinematic analysis of the linkage, and the motion was simulated using the RoboAnalyzer program. For the forward and reverse kinematic analysis, ABB IRB 6700 robot was chosen, and the identical D-H parameters were utilized to establish the robot's initial motion simulation in the software. The joints are moved with a cycloidal trajectory in order to calculate the forward kinematics. In comparison to other trajectories, this trajectory takes less time overall. Furthermore, the robot moves smoothly and vibration-free along its cycloidal track.

When the results of MATLAB codes for the forward dynamics of any 6-DoF joints are compared to those of Robo-Analyzer software, it is discovered that the same findings demonstrate the validity of the methodology employed. Additionally, the RoboAnalyzer for 6R robot's inverse kinematics module is used to carry out the inverse kinematics owing to space constraints therefore, the full forward and inverse kinematic equations are not provided in this study. The equations were solved using MATLAB programming, and conclusions were reached. The Robo Analyzer software was utilized to verify these outcomes. The kinematic analysis framework was validated because the two outcomes were almost identical. We will next attempt to confirm the findings using real robot motion. The findings provide a robust foundation for integrating the ABB IRB 6700 into industrial automation workflows where precision, repeatability, and trajectory optimization are essential. The proposed methodology can assist engineers in offline programming, robot calibration, and workspace planning. Additionally, the use of simulation prior to deployment can significantly reduce commissioning time and improve system reliability in

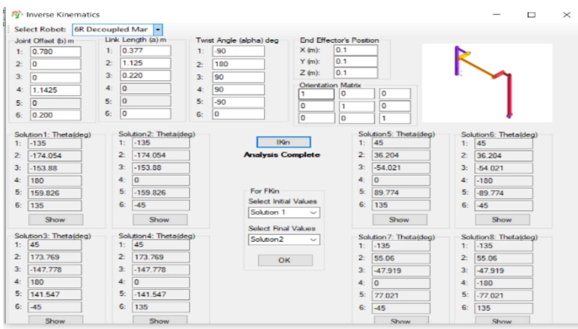

Fig. 9: Inverse kinematics ABB IRB 6700 robot

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applications such as welding, material handling, and arc milling.

Future research could focus on:

1) Extending the current analysis to include dynamic modeling and control, incorporating torque and force considerations.
2) Implementing real-time trajectory optimization under constraints such as collision avoidance and joint limits.
3) Conducting experimental validation with a physical ABB IRB 6700 robot to bridge the gap between simulation and real-world deployment.
4) Exploring machine learning approaches for adaptive inverse kinematics in unstructured or dynamic environments.

The rationale for this study lies in addressing the critical need for accurate and application-oriented kinematic modeling of industrial robots, specifically the ABB IRB 6700. As modern manufacturing environments demand greater precision, speed, and adaptability, understanding both forward and inverse kinematics becomes essential for optimizing robotic performance. The analysis presented in this paper not only demonstrates the mathematical modeling of the robot's motion but also validates these models through simulation tools such as MATLAB and RoboAnalyzer. This dual approach offers practical benefits, including reduced programming errors, shorter commissioning times, and enhanced offline planning capabilities. Economically, the ability to simulate and refine robotic tasks prior to deployment translates into significant savings in production downtime and resource utilization. Realistically, the proposed methodology supports scalable implementation across various industrial settings, making it a valuable reference for both academic research and industrial automation applications.

Abbreviation Table

Abbreviation Used	Full Form
D-H	Denavit–Hartenberg
DOF	Degrees of Freedom
EE	End-Effector
FKN	Forward Kinematics
IKN	Inverse Kinematics
JV	Joint Variable
TM	Transformation Matrix
6R	6 Revolute Joints

References

1) A.F. Nicolescu, "Industrial Robots," EDP Publishing House, Bucharest (2005).
2) G. Khushdeep, D. Sethi, "An analytical method to find workspace of a robotic manipulator," J. Mech. Eng., 41(1), pp. 25–30 (2010). DOI: 10.3329/jme.v41i1.5359
3) T. Yong, F. Chen, X. Hegen, "Kinematics and workspace of a 4-DOF hybrid palletizing robot," Adv. Mech. Eng., 20, (2014). DOI: 10.1155/2014/125973.
4) S. Srikanth, M. Sravanth, V. Sreechand, K.K. Kumar, "Kinematic analysis of 3 DOF serial robot for industrial applications," Int. J. Eng. Trends Technol., 4(4), pp. 1000–1004 (2013).
5) K.K. Kumar, A. Srinath, G. Jugalanvesh, P. Premsai, M. Suresh, "Kinematic analysis and simulation of a 6 DOF KUKA KR5 robot for milling application," Int. J. Eng. Res. Appl., 3(2), pp. 820–827 (2013).
6) C. Zhang, et al., "Innovative inverse kinematics algorithm for 6-DOF robotic manipulators with offset wrists," Sci. Rep., 15, pp. 1–12 (2025). DOI: 10.1038/s41598-025-19054-y
7) A.M. Ivan, "Research on optimization of industrial robots operation for machining processes," PhD Thesis, Univ. Politehnica Bucharest (2011).
8) Y. Xu, M.C. Nechyba, "Fuzzy inverse kinematic mapping: rule generation, efficiency, and implementation," Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst., 2, pp. 911–918 (1993).
9) M. Dahari, J. Tan, "Forward and inverse kinematics model for robotic milling process using KR-16KS KUKA robot," Proc. 4th Int. Conf. Model. Simul. Appl. Optim., pp. 1–6 (2011). DOI: 10.1109/ICMSAO.2011.5775598
10) R.N. Jazar, Theory of Applied Robotics, Vol. 1, Springer, Berlin (2010).
11) S.K. Saha, Introduction to Robotics, 2nd ed., Tata McGraw-Hill, New Delhi (2014).
12) M.P. Groover, Industrial Robotics, 2nd ed., McGraw-Hill, New York (2012).
13) D. Pieper, "The kinematics of manipulators under computer control," PhD Thesis, Stanford Univ., Stanford (1968).
14) ABB Robotics, *Product specification book manual IRB 1520*, http://www.abb.com/Document ID: 3HAC043437-001 (2012–2019).
15) J.J. Craig, Introduction to Robotics: Mechanics and Control, Pearson/Prentice Hall, Upper Saddle River, NJ (2005). https://doi.org/10.1109/JRA.1987.1087086
16) R.P. Paul, Robot Manipulators: Mathematics, Programming and Control, MIT Press, Cambridge, MA (1981).
17) M. Raghavan and B. Roth, "Inverse kinematics of the general 6R manipulator and related linkages," *ASME Journal of Mechanical Design*, 115(3) (1993) 502–508.
18) S.S. Sinha, R.G. Chittawadigi, and S.K. Saha, "Inverse kinematics for general 6R manipulators in RoboAnalyzer," *5th Joint International Conference on Multibody System Dynamics*, June 24–28, 2018, Lisbon, Portugal.

Cite: S. Chauhan, N. Gupta, A. Mishra, "Forward and Inverse Kinematics analysis of the ABB IRB 6700 Industrial Robot". Evergreen, 13 (01) 256-266 (2026). https://doi.org/10.5109/7411067.

19) A. Patwardhan, A. Prakash, and R.G. Chittawadigi, "Kinematic analysis and development of simulation software for Nex Dexter robotic manipulator," *Procedia Computer Science*, 133 (2018) 660–667.
20) S.S. Chauhan and A.K. Khare, "Kinematic analysis of the ABB IRB 1520 industrial robot using RoboAnalyzer software," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, 7(4) (2020) 510–518. https://doi.org/10.5109/4150470
21) R.G. Chittawadigi, A. Jain, S.V. Shah, and S.K. Saha, "Recursive robot dynamics in RoboAnalyzer," *Proceedings of the 15th National Conference on Machines and Mechanisms*, Chennai, India, Nov. 30–Dec. 2, 2011, 482–490.
22) S.S. Chauhan and S.C. Bhaduri, "Structural analysis of a four-bar linkage mechanism of prosthetic knee joint using finite element method," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, 7(2) (2020) 209–215. https://doi.org/10.5109/4055220
23) S.S. Chauhan and A.K. Khare, "Analysis of four-bar linkages suitable for above-knee prosthesis," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, 9(3) (2022).
24) S.S. Chauhan, "Kinematic and kinetic gait analysis of bilateral knee osteoarthritis and its effects on ankle and hip gait mechanics," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, 7(3) (2020) 359–365. https://doi.org/10.5109/4068617
25) S.S. Chauhan and S.C. Bhaduri, "Analysis of four-bar linkages configurations for above-knee prosthesis status," *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy* (2021). https://doi.org/10.5109/4055220
26) M. Buss, "Fast inverse kinematics techniques for real-time reaching tasks," *IEEE Transactions on Robotics* (2014).
27) R.S. Andersen and D. Kraft, "Optimal control of industrial robots with computational complexity constraints," *Proceedings of IEEE International Conference on Robotics and Automation (ICRA)*, 370–375 (2008).
28) W. Khalil and E. Dombre, *Modeling, Identification and Control of Robots*, Butterworth-Heinemann, Oxford, UK (2002).
29) J. Piepmeier, B.E. Bishop, and G. Niemeyer, "An actuated finger with optimal open-loop stiffness characteristics," *IEEE Transactions on Robotics and Automation*, 20(4) (2004) 750–757.
30) B. Siciliano, L. Sciavicco, L. Villani, and G. Oriolo, *Robotics: Modelling, Planning and Control*, Springer, London, UK (2009).
31) L. Sciavicco and B. Siciliano, "A solution algorithm to the inverse kinematic problem for redundant manipulators," *IEEE Journal of Robotics and Automation*, 4(4) (1996) 403–410. https://doi.org/10.1109/56.804
32) A. Gupta and P. Jain, "RoboAnalyzer: 3D model based robotic learning software," *Proceedings of the IEEE International Conference on Technologies for Practical Robot Applications (TePRA)* (2011).
33) A. Gupta and P. Jain, "Simulation and analysis of industrial robots using RoboAnalyzer," *International Journal of Mechanical Engineering and Robotics Research*, 2(4) (2013) 10–15.

Cite: S. Chauhan, N. Gupta, A. Mishra, "Forward and Inverse Kinematics analysis of the ABB IRB 6700 Industrial Robot". Evergreen, 13 (01) 256-266 (2026). https://doi.org/10.5109/7411067.